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# MIRANDA DATA PROCESSING — INTERFACES

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by

(10) E.U. Trevorrow

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Miranda was a low-orbit technology satellite carrying a number of experimental packages. In order to realise the planned experimental objectives it was necessary to employ a sophisticated real-time control system requiring inputs that could only be determined by independent operational-support software. The analysis of the experimental data also called for a considerable amount of data processing software, as did the general housekeeping procedures. A comprehensive software system was developed to cover these requirements, so that a thorough appreciation was needed of all software system interfaces.

This Report defines the satellite, operational, computer-system and experimental interfaces with which the software had to be compatible.

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# ROYAL AIRCRAFT ESTABLISHMENT

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## MIRANDA DATA PROCESSING - INTERFACES

by

E. U. Trevorrow

SUMMARY

Miranda was a low-orbit technology satellite carrying a number of experimental packages. In order to realise the planned experimental objectives it was necessary to employ a sophisticated real-time control system requiring inputs that could only be determined by independent operational-support software. The analysis of the experimental data also called for a considerable amount of data processing software, as did the general housekeeping procedures. A comprehensive software system was developed to cover these requirements, so that a thorough appreciation was needed of all software system interfaces.

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Departmental Reference: Space 518

## LIST OF CONTENTS

## 1 INTRODUCTION

Miranda, previously known as X4 [1], the second satellite in the United Kingdom Space Technology Programme, was successfully launched in a southerly direction from the Western Test Range California by an Algol III Scout on 9 March 1974. Miranda, designated 1974-13A, was the first British three-axis-stabilised satellite and was placed into a sun-synchronous orbit of inclination 97.8°, with an apogee height of 930 km and a perigee height of 720 km. Despin, separation and sun-lock were all achieved automatically.

Miranda had an experimental attitude control system, and carried experimental infra-red, albedo, and star sensors. The attitude control system maintained the pitch axis and solar arrays sun-pointing and controlled the motion about the pitch axis. The experimental sensors were fixed to a common mounting plate, with the star sensor positioned on the dark side of the satellite. The satellite was designed to work for at least six months in a fully sunlit orbit and it actually ceased to function after nine months, during the last month of which the orbit was partially eclipsed.

An early decision was taken to carry out all data-processing and operations-support tasks using the computer in the RAE Control Centre, which was dedicated to Miranda operations. Thus the Control Centre, operations personnel, experimenters, technical advisers and all data processing activities were internal to Space Department.

The philosophy adopted for data processing was to develop a modular system which would be easy to use, yet straightforward to modify as required. The overall system design was therefore optimised instead of just the software segment. In the event, this proved very successful and all data-processing objectives for Miranda were completed by 1 March 1975, less than one year after launch. To achieve this, all relevant interfaces had to be clearly defined and understood. This Report defines the satellite, operational, computer-system and experimental interfaces with which the software for both data processing and operational support had to be compatible. A further report [2] gives details of the programs that were used.

## 2 SATELLITE INTERFACES

A concise but comprehensive understanding of the satellite systems was required when designing the software system for data processing and operations support. In particular this related to the experimental objectives, the modes

of operation and the orbit of the satellite. In general it was not necessary to have any deep understanding of the internal workings of sub-systems, since there was a group of sub-system technical advisers who could be called upon for assistance if required.

## 2.1 Satellite systems

An outline of the satellite and its axis-system is given in Fig 1. The attitude control system maintained the pitch axis in the sun-pointing direction, thus keeping the solar paddles facing the sun. Motion about the pitch axis was controlled by the pitch gyroscope. Several pitch rates were available and could be selected by ground command, viz:

| | |
|---|---|
| Prime rates | $0^{\circ}/h$ |
| | $\pm 8^{\circ}/h$ |
| | $\pm 12^{\circ}/h$ |
| | $\pm 217^{\circ}/h$ ($-217^{\circ}/h$ being the nominal orbital rate). |
| Pitch integrator | $-30$ to $+30^{\circ}/h$ (12-bit register, 1 bit for sign). |

Any non-redundant combination of prime rates could be set by ground command and any pitch integrator setting could be superimposed.

There were several modes of operation of the satellite:

| Mode | Description |
|---|---|
| 0 | Launch |
| 1 | Yo-yo despin |
| 2 | Sun acquisition |
| 3 | Inertial sun-lock |
| 3A | Mode 3 back-up |
| 4 | Earth reference |
| 5 | Star acquisition and lock (active) |
| 5A | Inertial star lock (passive) |
| 6 | Star scan |
| 8 | Emergency - roll/yaw fault detected |
| 8A | Emergency - pitch fault detected |
| 9A | Mode 4 back-up |

Most of the useful experimental data was obtained when the satellite was in Mode 3. In this mode, sun reference was provided by the fine sun sensor and the attitude control system maintained the satellite sun-pointing to an accuracy of 1½ arcmin. Occasionally, useful experimental data was obtained when the

satellite was in Modes 2 and 3A. In these modes the prime sun sensor was selected, which, due to its wide-angle field of view, suffered from albedo contamination over part of the orbit. This drastically degraded the sun-pointing accuracy and hence the attitude data. Thus only those requirements which could tolerate low attitude-accuracy were satisfied in these modes.

Modes 4 and 9A were not used; instead, earth reference was achieved by finely compensating the nominal orbital rate with pitch-integrator adjustments when the satellite was in Mode 3. This method was more satisfactory, since accurate attitude determination was achievable. When the satellite was operating in Modes 0, 1, 8 and 8A, the data obtained was of little use for experimental analysis.

The satellite carried a package of experimental sensors, which are detailed in section 5. All absolute pitch attitude references were obtained by analysis of the data from these sensors.

A detailed knowledge of the telemetry data sub-system was required and this is discussed in section 2.5. In general, however, no other detailed sub-system knowledge was required in order to furnish technical advisers with processed sub-system data.

## 2.2 Orbit

The satellite was launched on 9 March 1974 into a fully sunlit orbit with an inclination of $97.8^{\circ}$ and with the equatorial crossings close to the terminator. The orbital height of the satellite was about 930 km at apogee and about 720 km at perigee. The inclination caused the orbital plane to rotate about the earth's polar axis at a rate of about $0.89^{\circ}$/day, while the direction of the sun was moving at about $0.99^{\circ}$/day. (The ideal orbital inclination was $98.4^{\circ}$, since the orbital plane would then have rotated at the same rate as the sun direction.) Consequently, the satellites orbit remained fully sunlit for about eight months. During that time the inclination of the orbital plane to the plane of the terminator varied between 3 and $27^{\circ}$.

## 2.3 Passes

The telemetry and telecommand station for Miranda was situated at Lasham (latitude $51.19^{\circ}$, longitude $-1.03^{\circ}$) some 22 km from the Control Centre at RAE. Since the orbit was close to polar and the inclination of the orbital plane to the terminator plane was small, the satellite was in view of the ground station during those orbits within a few hours of dawn and dusk. The set of passes for a typical day is given in the following table.

1974 Day No.86 (27 March)

| Pass | Times (rise-set) | Maximum elevation |
|---|---|---|
| $M_1$ | 03.32-03.44 | 18.1° |
| $M_2$ | 05.10-05.25 | 78.9° |
| $M_3$ | 06.52-07.04 | 17.2° |
| $E_1$ | 17.21-17.34 | 23.7° |
| $E_2$ | 19.01-19.14 | 51.8° |

On most days, satellite passes with sufficient elevation for operational use occurred during two or three consecutive orbits each morning and evening, but occasionally the satellite was visible with sufficient elevation for four consecutive orbits. The scheduling of passes is discussed in Ref 3.

## 2.4 Orbital elements

SDC elements[4] were available for the satellite from within a few hours of launch. After the first few days of life, new elements were made available weekly. These elements were necessary for pass prediction purposes, but had limitations when more accurate orbital reconstruction was required for experimental sensor analysis. More accurate elements (referred to as RAE elements) were obtained, therefore, by the use of the RAE orbit determination program PROP[5], but with a delay of some four to six weeks while observations were obtained from the US Naval Research Laboratory.

## 2.5 Telecommand

The system employed to send commands to the satellite conformed to the NASA Tone Digital Command Standard which meant that all commands were single-action. Some of these commands could be sequenced together, however, to select, fill and execute one of a pair of 16-bit on-board command registers, so that there were effectively commands of two types, known as 'direct' and 'multiple'. The command registers, known as Register A and Register B, permitted the commanding of elaborate attitude control system operations from the Control Centre.

Using automatic control procedures, two multiple commands could be executed and verified within a few seconds, by loading both the A and B registers prior to the execution of either. However, execution of further multiple commands was limited by the time taken to refill registers. The automatic procedures allowed for multiple commands to be executed at selected times by previously filling a register and sending the execute command at the specified time.

## 2.6 Telemetry

The satellite had a single data stream which could be commanded into 'direct', 'record' or 'playback' mode. Since the satellite was out of range of the ground station for most of the time, the normal operational mode was 'record', during which no data could be transmitted. During a pass, the mode was changed by ground command in the following sequence: DIRECT-PLAYBACK-DIRECT-RECORD. The format of the telemetry data was the same in direct and recorded modes, the direct data rate being 32 times the recorded data rate. The speed of the tape was increased by a factor of 32 for playback. Thus during a pass all data was transmitted at the same rate, viz 2048 bits/second.

A minor frame of data consisted of 128 8-bit syllables, giving a time for the transmission of each minor frame of 0.5 second. There were eight minor frames in a major frame.

There were two tape recorders for the recorded data, each of which contained read, erase and write heads. Only one of the tape recorders could be used at any time, but commands existed for switching to the other if desired. The one in use recorded data on a continuous loop of tape which was overwritten every 122 minutes, playback taking 230 seconds. When data had been recorded for less than 122 minutes, the remainder of the tape was blank.

### 2.6.1 Timing of data

During a pass, the time was read automatically from the Control Centre clock at the end of receipt of each minor frame of data, and was transferred to magnetic tape with the frame of data. The time was binary-coded-decimal, as specified in section 4.6. This time was adjusted to the start of a minor frame and was then ready for use in the processing of direct data. For recorded data the time written onto the data tapes was the time of playback and was of little use except on the few occasions when no data was taken from the satellite for a period of more than 18 hours - it was then used to resolve the ambiguity due to recycling of the frame counter.

For the timing of recorded data the satellite telemetry system had a 12-bit frame counter which was sampled each minor frame. When the telemetry data system was commanded into record mode, at the end of each pass, the frame counter was set to zero. The time of this command was inserted into the header of the next pass of data (on a digital magnetic tape). The actual time of recorded data could then be evaluated for each minor frame, using the frame counter in recorded data as a clock to provide time relative to the recorded data command time.

This method of timing of recorded data caused many operational problems, since it was not possible to automate the procedures for the transference of the record-command times to the standard data tapes, and on occasions the estimation of this time was suspect. In retrospect these problems could have been avoided with very little extra satellite hardware if the following method had been used:

(i) the counter had been an 18-bit clock-counter (incrementing by 1 every half-second, ie the period of a direct-data minor frame) - instead of the 12-bit minor-frame counter (which incremented by 1 for each frame of either direct or recorded data);

(ii) the switching to and from direct and recorded data had been synchronised with the clock counter - instead of at the time of receipt of command to direct or recorded data.

The value of the counter in every minor frame of data from a pass would then have given the time relative to a single time-base, which could have been evaluated simp'y and reliably from the timing data automatically written onto the standard data tapes within that pass.

The following items were taken into consideration when evaluating the time of the start of a minor frame:

| | |
|---|---|
| transmission delay from satellite | 3-9 ms, |
| transmission delay to satellite at $12^{\circ}$ | 6-7 ms, |
| command duration | 226 ms, |
| link delays between Lasham and control centre | 12 ms, |
| command initiation software timing delay | 1 ms. |

The time associated with an individual syllable of data was given by

$$T_0 + n\delta t ;$$

where n was syllable count;

$T_0$ was time at start of minor frame (actually syllable 0);

$$\delta t \text{ was } \begin{cases} 2^{-8} \text{ s - direct data} \\ 2^{-3} \text{ s - recorded data.} \end{cases}$$

### 2.6.2 Error detection

The telemetry data contained a primitive error detecting code in each minor frame of data. The real-time software (see section 3.6) checked each minor

frame of data with respect to the code and producea a checkword which was written onto the digital tapes with each minor frame of data (see section 4.6).

In the data processing the checkword was in general used to exclude all data from a faulty minor frame, but in the provision of data lists was used to tag data from a faulty minor frame. Hence simple algorithms could be used with complete reliability. (In the absence of error detection, highly complex algorithms would have been required, and these would not have been completely reliable.)

### 2.6.3 Calibrations

The first items to be calibrated were the analogue-to-digital converters of the satellite data tray. They were found to be the same to better than 1 mV and the calibration used was:

$$v = -0.03926N + 5.024$$

where $N$ $(0 \leq N \leq 255)$ was the digital output (or telemetry sample) and $v$ the input voltage.

The Operations Manual contained a section giving the calibrations of all those performance parameters where it was feasible to perform pre-launch calibrations. The calibration curves were also fitted by polynomials of degree one, two or three as appropriate. Certain parameters, such as pitch rate and gyro drift rate, could only be calibrated satisfactorily when the satellite was in orbit.

The satellite contained two clocks, designated A and B. Their nominal frequency was $2^{21}$ Hz which corresponded to a telemetry data rate of exactly 2048 bits/second. In practice the actual measured values were used, viz:

$$\text{Clock A: } 2^{21} + 104 \text{ Hz}$$
$$\text{Clock B: } 2^{21} + 96 \text{ Hz.}$$

Just before launch the alignment between the gyro pack and the sensor mounting block was checked and found to be within seconds of arc. Appropriate details of the orientation measurements of the sensors on the mounting block are given in section 5.

## 2.7 Earth/sky coverage

The data received from the satellite during a group of (morning or evening) passes covered the period from 122 minutes prior to first-pass replay up to the end of the last pass. Since Lasham was the only ground station used for the

collection of telemetry data, the data from the satellite experiments was mainly limited to periods when the satellite was within $25^{\circ}$ of the plane of the Greenwich meridian. Since (i) the satellite was sun-pointing, (ii) the orbital plane was close to the terminator and (iii) the plane containing the sight lines of the experimental sensors was perpendicular to the sun line, it followed that the areas on the ground observed by the sensors fell into that same $\pm 25^{\circ}$ band. The star sensor experiments did not suffer this restriction however, since the available band of observation rotated as the satellite orbit rotated. In a period of six months, the whole sky was swept by the star sensor.

## 3 OPERATIONS INTERFACES

The operations plan for the satellite was ambitious and the effort available for the provision of software for data processing and operations support was relatively limited. To ensure that the available resources were used effectively, the data processing section maintained close liaison with the operations group, and in particular with the Satellite Controller and the Experiment Co-ordinator, throughout the lifetime of the satellite.

### 3.1 Satellite Controller

The Satellite Controller was in charge of all operational activities relating directly to the satellite and ground support equipment. He was appointed nearly three years before launch and during that period was a technical adviser to the Miranda project management with special responsibility for assembly integration and test. In that capacity he was able to gain an intimate knowledge of the spacecraft, this being essential for the effective performance of his duties as Satellite Controller.

It was his responsibility to ensure that the satellite operated according to the operational plan, and to take action, should it be necessary, to maintain the safety of the satellite. He also co-ordinated all Control Centre activity, including the running of all data processing programs.

### 3.2 Experiment Co-ordinator

The Experiment Co-ordinator integrated the various requirements of the particular experimenters into the broad-line operations plan to form detailed plans for the pass-by-pass operation of the satellite. These plans were used by the Satellite Controller to produce pass schedules. The Experiment Co-ordinator also had to ensure that any special software required before or after a pass, for the operational support of a particular activity, was made available.

### 3.3 Operations personnel

The Control Centre was manned by contractor staff throughout the lifetime of the satellite. In particular, they operated the computer during satellite passes, organised the data archive and ran all data processing programs. Thus appropriate operating instructions had to be formally specified by the data processing section.

### 3.4 Technical advisers

During the procurement of the satellite, a number of RAE personnel acted as technical advisers to the project management. They continued in this role after launch, giving technical advice to the Satellite Controller. They required information regularly after satellite passes, so that:

(i) they could alert the Satellite Controller of any unexpected occurrences or trends that might otherwise have been overlooked;

(ii) they were in a position to advise the Satellite Controller on a course of action in the event of an anomaly.

### 3.5 Operations plan

Prior to launch the major objectives for the satellite were formulated into a broad operations plan, with a detailed plan for the first week of operation. After this it was necessary to maintain maximum flexibility in the detailed planning, since certain systems on the satellite did not perform quite as expected. However, some systems proved much more accommodating than specified - with flexible operational planning full advantage was taken and the pre-launch objectives were fully satisfied.

### 3.6 Real-time activities

In the set-up phase for a pass, the information from the pass schedule was fed into the computer interactively by the operator; this included the information which was written into the magnetic tape header blocks.

During a pass the data from the satellite was digitised and written onto magnetic tape. With each minor frame of data, the time given by the control centre clock, the frame count, a data checkword, and 10 extra words, were also written to the magnetic tape. The time corresponded to the end of the receipt of a minor frame, and the extra words gave the status of ACS 'command-sending' during that minor frame.

Occasionally it was not possible to produce a digital tape in real-time, in which case it was produced subsequently from raw data recorded in real-time. This fact was indicated in the header for that pass. The format of the magnetic tape is defined in section 4.6.

Any further description of the real-time system[3] is beyond the scope of this Report, as it is intended here only to cover the interfaces for the data-processing and operational-support software with the real-time activities.

## 3.7 Supporting activities

In addition to real-time software for the operational control of the satellite, the operations group required support software for pre-pass and immediate post-pass analysis. This included satellite pass predictions, the provision of performance parameter lists, and the evaluation of command patterns for attitude maneouvres and of optimum sensitivity settings for sensors.

## 3.8 Special data forms

For certain of the programs and activities it was essential for the operator to load a considerable amount of information into the computer. In each of these cases, a special data sheet using a simple format was designed, which was then used for program specification.

## 3.9 Satellite documentation

As part of their pre-launch activities, the operations group compiled a Satellite Operations Manual. This abstracted and formalised information contained in the many volumes of contractor documentation, together with sections on the real-time software control system. The manual contained all the essential information (including contingency procedures) for operating Miranda and the Control Centre. With regard to data processing it included sections on parameter calibrations, telemetry format and command system.

# 4 COMPUTER SYSTEM INTERFACES

The Control Centre was divided into three areas; first a central area, which was the main control room housing the telemetry equipment, the operations console and lineprinter; secondly, an inner area which housed the main part of the computer system including the disc stores, magnetic tape-decks and tapes; and thirdly an outer area, which was the experimenters' room, and was also used as a viewing room. The central and inner areas were controlled for temperature and humidity.

### 4.1 Ground network

Operational control of Miranda was from the Control Centre in Space Department RAE, in conjunction with the telemetry and telecommand station at Lasham, 22 km away. Telemetry data was received at Lasham and sent in real-time via a modern link to the control centre, for processing and data evaluation. Command instructions were initiated at the Control Centre either automatically or by operator action and were sent by a specially protected land-line link to Lasham (see Fig 2 for details). After the launch phase, when the NASA ground station at Tananarive was used, Lasham was the only ground station used for the collection of telemetry data. As a back-up to Lasham for telecommand, there was a command aerial at RAE.

### 4.2 Computer system

The Control Centre computer was an EMR 6130. Its main data processing features were:

Fortran compiler (with in-line coding)
32K 16-bit words of core
$775 \times 10^{-9}$ s cycle-time
Teletype consoles with on-line editing
Paper tape reader and punch
Three magnetic tape decks
Two 1.6-megaword fixed-disc stores
Lineprinter

### 4.3 Program files

Both magnetic tapes and disc files were used for storing the computer programs. The amount of disc space available was limited. This was tailored in such a way that each program for operational support had its own special disc files named with the abbreviated program name. Other programs were stored on magnetic tape. The programs were stored in binary, and only simple 'load and go' instructions were required to use them. Source versions of each program were also stored on magnetic tapes.

### 4.4 Operating instructions

For each program a sheet of operating instructions was provided. In general these were very simple, and in many cases the software system was explicitly designed to provide this simplicity. The instructions were kept in a supplement to the Satellite Operations Manual.

## 4.5 Data archive

All data received from the satellite during a pass was digitised and written on magnetic tape. After the pass the data was appended onto a master tape. There was one master tape for each day and this contained between four and seven passes of data. There were thus about 240 master tapes covering the satellite's operational lifetime.

## 4.6 Magnetic tape format

### 4.6.1 Block structure

| | |
|---|---|
| A digital magnetic tape consisted of: | one or more passes of data; |
| followed by: | a tape-mark. |

| | |
|---|---|
| A pass of data consisted of: | a header; |
| followed by: | one or more data blocks; |
| followed by: | a tape-mark |

### 4.6.2 Header

This consisted of: 10 blocks of text data:-

| Block | Contents |
|---|---|
| 1 | X4VHEADER |
| 2 | 1974VDAYV followed by left-justified Day No. (1, 2, or 3 digits) |
| 3 | 4-digit orbit number (right-justified) |
| 4 | M or E followed by 1, 2, 3 or 4 |
| 5 | Time of acquisition of signal in format HHVMMVSS |
| 6 | 1 : digital tape made on-line<br>0 : digital tape made off-line |
| 7 | Day No. right-justified (3 digits) of time of last command to record |
| 8 | Time of last command to record in format HHVMMVSS.sss |
| 9 | 3-digit analogue tape number (right-justified) |
| 10 | 9999 |

### 4.6.3 Data block

This consisted of: 143 16-bit words:

| Word | Contents |
|---|---|
| 1-125 | syllables 003-177 (octal) of a minor frame |
| 126-128 | the subsequent sync code pattern of a minor frame |
| 129-131 | time of year in a 48-bit pattern<br>bits 1-6 : undefined<br>bits 7-8 : hundreds of days<br>bits 9-12 : tens of days<br>bits 13-16 : units of days<br>bits 17-18 : tens of hours<br>bits 19-22 : units of hours<br>bits 23-25 : tens of minutes<br>bits 26-29 : units of minutes<br>bits 30-32 : tens of seconds<br>bits 33-36 : units of seconds<br>bits 37-40 : undreds of milliseconds<br>bits 41-44 : tens of milliseconds<br>bits 45-48 : units of milliseconds |
| 132 | the frame counter |
| 133 | 0 : frame not checked, 1 : frame checked |
| 134-143 | 10 extra words for command information, see Appendix C. |

## 5 EXPERIMENTS INTERFACES

There were five experimental packages on the satellite, each under the control of a prime experimenter with whom close co-operation was maintained at all times to determine methods of analysis and to finalise details of all objectives. The five packages were known as Experiments A, B, C, D and E.

The experimental sensors (Experiments B, C and D) were fixed to a common mounting plate to provide stability with the star sensor positioned on the dark side of the satellite. Their fields of view were nominally in the yaw-roll plane of the satellite as shown in Fig 3. The angles given in the figure are nominal values, the actual measured angles of the flight model being used in practice, as given in the table below. (The angles are measured as positive rotations about the pitch axis, starting from the yaw direction.)

| | |
|---|---|
| $IR_1$ | $-116°30'$ |
| $IR_2$ | $-116°31'$ |
| $IR_3$ | $-105°59'$ |
| $IR_4$ | $+109°59'$ |
| Star sensor | $-70°02'$ |
| Albedo sensor (nth element) | $+108.742 + 0.22783\,n$ degrees. |

## 5.1 Experiment A - Attitude control system[6] (ACS)

The main mode of attitude control used a set of rate-integrating gyroscopes as a three-axis attitude reference. Control torquing was provided by a propane gas-jet control system. A novel form of processing the attitude measurement signals was employed: incorporation of a model of the satellite dynamics led to a high quality of estimation of angular velocity, with the result that the precision of the limit-cycle control which was achieved closely approached the limit of practicability, given the inherent limitations of a gas-jet system. In two axes (roll and yaw) the gyroscope reference was updated by signals from a fine sun sensor, so that sun-pointing of the pitch axis was achieved as the principal control activity. Pitch axis control (about the sun-line) was referred, for the most part, solely to the gyroscope. A variety of pitch-rate biases (see section 2.1) could be applied to this gyroscope in order to exercise the three attitude sensing Experiments, B, C and D, all of which were responsive primarily to pitch attitude. However, a mode of control was provided to permit the pitch gyro to be updated by the star sensor (Experiment C), so that star-lock could be achieved.

The objectives of the experiment were:

(i) to provide in-orbit operation of important components, notably the gyroscopes and the propane gas-jet system;

(ii) to obtain national experience of the design of a high-precision three-axis active attitude-control-system;

(iii) to provide essential services for the other experiments and for the satellite as a whole.

## 5.2 Experiment B - Infra-Red sensor[7]

The infra-red sensor consisted of four separate pyroelectric detectors ($IR_1$, $IR_2$, $IR_3$ and $IR_4$) which operated in the 14-16μm wavelength band. The centre-line directions of the fields of view are shown in Fig 3.

The objectives of the experiment were:

(i) to gain operational experience of the performance of the pyroelectric detectors;

(ii) to map the infra-red radiation over those parts of the earth accessible to the sensor during the lifetime of the satellite;

(iii) to evaluate the characteristics of the sensed infra-red radiation with respect to elevation, earth position relative to sun, and season;

(iv) to characterise the shape of the sensed infra-red radiation relative to horizon height, when the satellite was in star-lock;

(v) to give attitude information in support of the whole experimental programme.

### 5.3 Experiment C - Star sensor[8] (Canopus)

The star sensor had a split-image detector which could be used to measure star signal intensity or to provide a control reference for locking onto a selected star. The light entering the star sensor was reflected by a mirror onto the detector. When the mirror was in the central position, the centre-line field of view of the sensor was in the roll-yaw plane, as shown in Fig 3. The total angular field of view in the plane was $3^{\circ}$, which was split into two equal parts by the detector. In order to observe many stars at different times of the year the mirror could be rotated into 11 open positions, giving the series of values tabulated below for the angle between the pitch axis (sun-direction) and the centre-line of sight of the sensor.

| Position No. | Angle ($^{\circ}$) |
|---|---|
| 1 | 105 |
| 2 | 102 |
| 3 | 99 |
| 4 | 96 |
| 5 | 93 |
| 6 | 90 |
| 7 | 87 |
| 8 | 84 |
| 9 | 81 |
| 10 | 78 |
| 11 | 75 |

The width of the field of view about the axis of rotation of the mirror was $4^{\circ}$. There were three sensitivity settings which could be used, but almost invariably the most sensitive setting was in operation.

A glare detector was used to prevent exposure of the star sensor to earth albedo and moonlight. In star-lock mode (Mode 5) further protection could be obtained by using a signal from the infra-red sensor. This would allow the star-sensor signals to be used by the attitude control system only when $IR_4$ (which pointed in the opposite direction to the star sensor) was earth-pointing.

The experimental objectives were:

(i) to demonstrate star-lock capability;

(ii) to evaluate in-orbit signal characteristics from star mapping exercises and correlate with measurements made on the RAE star simulator before launch;

(iii) to evaluate the effects on performance caused by reflected light from dust particles, gas-jet efflux and satellite structure;

(iv) to provide very accurate attitude data when in star-lock for the infra-red horizon characterisation.

### 5.4 Experiment D - Experimental albedo sensor[9,10]

This sensor consisted of an array of 100 independent photodiode elements with non-overlapping fields of view and covering a total field of view of 22.8° as shown in Fig 3. The output from the detector was a set of 100 bits giving an 'ON' or 'OFF' state for each element. The detector had sensitivity settings which could be selected by ground command.

The experimental objectives were:

(i) to prove in-orbit operation of the detector and to correlate the attitude evaluation from the albedo detector with attitude evaluation from the other sensors;

(ii) to evaluate the brightness of albedo in the region of the terminator;

(iii) to evaluate the brightness variations along the terminator;

(iv) to provide attitude information in support of the star mapping exercises.

### 5.5 Experiment E - Solar cell patches

This experiment was a small part of a continuing programme of solar cell development and test. There were two small patches of experimental solar cells, mounted on the satellite solar arrays, each with a current and temperature monitor. The objective of the experiment was to monitor the variation in performance of the patches during the lifetime of the satellite.

## 6 CONCLUDING REMARKS

To satisfy the experimental and operational requirements mentioned in this Report, some 30 programs were written - these are described in Ref 2 together with a brief description of the way in which the software was structured within the programs.

For full details of the real-time satellite control system, Ref 1 should be consulted - this also contains full details of the telemetry data format and the sets of commands that were used to control the satellite.

## Appendix

### EXTRA WORDS

As specified in section 4.6, the digital magnetic tapes contained 10 extra words following each minor frame of data. For tapes made off-line the extra were all zero, but for tapes made on-line (in real-time) the extra words were used to give information on the status of ACS commands as follows:

extra words 1,2,3 were used for 'multiple' commands;
extra words 4,5 were used for 'direct' commands;
extra words 6-10 were spares.

At the start of a pass all extra words were set to zero, and not more than one extra word could change in value for each subsequent minor frame of data.

The extra word sequence for sending multiple commands was as follows:

$EW_1$ set to 0
$EW_3$ set to 0
$EW_2$ set to multiple-command register value

$$EW_1 \text{ set to} \begin{cases} \text{1 to indicate command was in Register A} \\ \text{2 to indicate command was in Register B} \end{cases}$$

$$EW_3 \text{ set to} \begin{cases} \text{1 to indicate command was executed} \\ \text{2 to indicate command was aborted.} \end{cases}$$

The extra word sequence for sending direct commands was as follows:

$EW_5$ set to 0
$EW_4$ set to 0

$$EW_5 \text{ set to} \begin{cases} \text{1 command 65 (override exlipse warning) expected} \\ \text{2 command 46 (Mode 2) expected} \\ \text{3 command 47 (Mode 8) expected} \\ \text{4 command 48 (Mode 8A) expected} \end{cases}$$

$$EW_4 \text{ set to} \begin{cases} \text{1 to indicate command was executed} \\ \text{2 to indicate command was aborted.} \end{cases}$$

In general the time elapsed between the expectation and execution of a command was small and thus a successful command was easily correlated with the telemetry data, giving full ACS status which was not directly available from the telemetry data.

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*Reports quoted are not necessarily available to members of the public or to commercial organisations.*

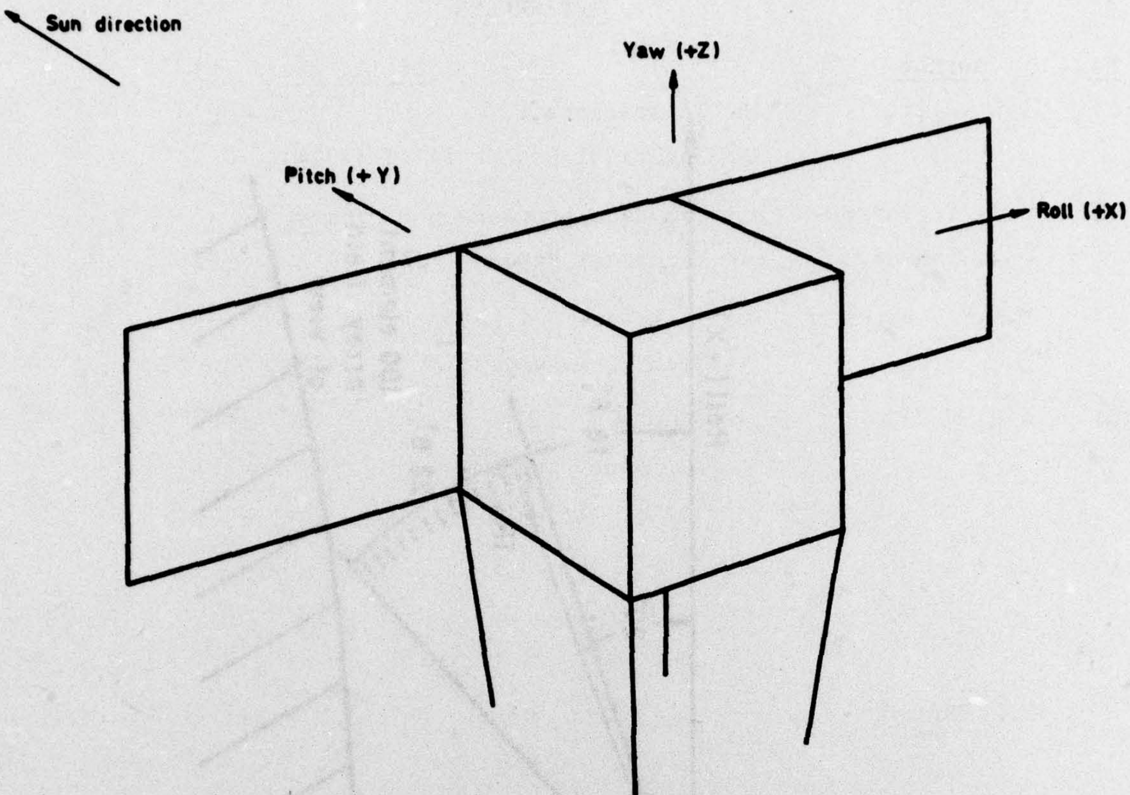


Fig 1 Satellite axis system

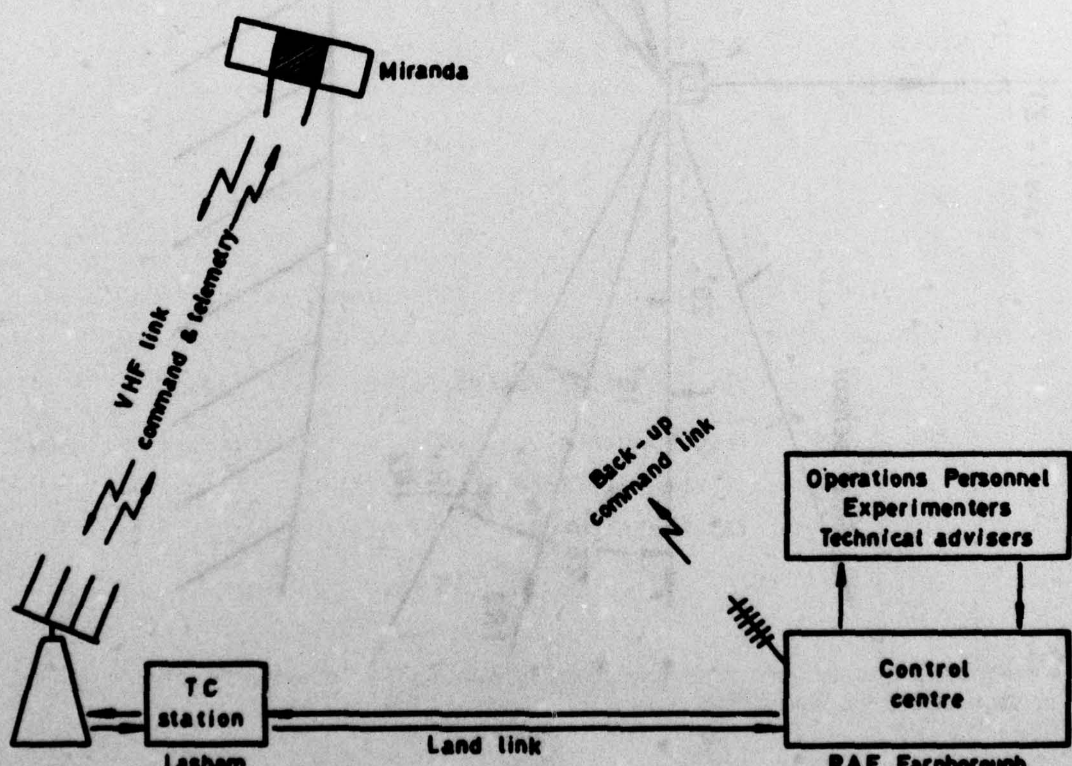


Fig 2 Miranda control and data system

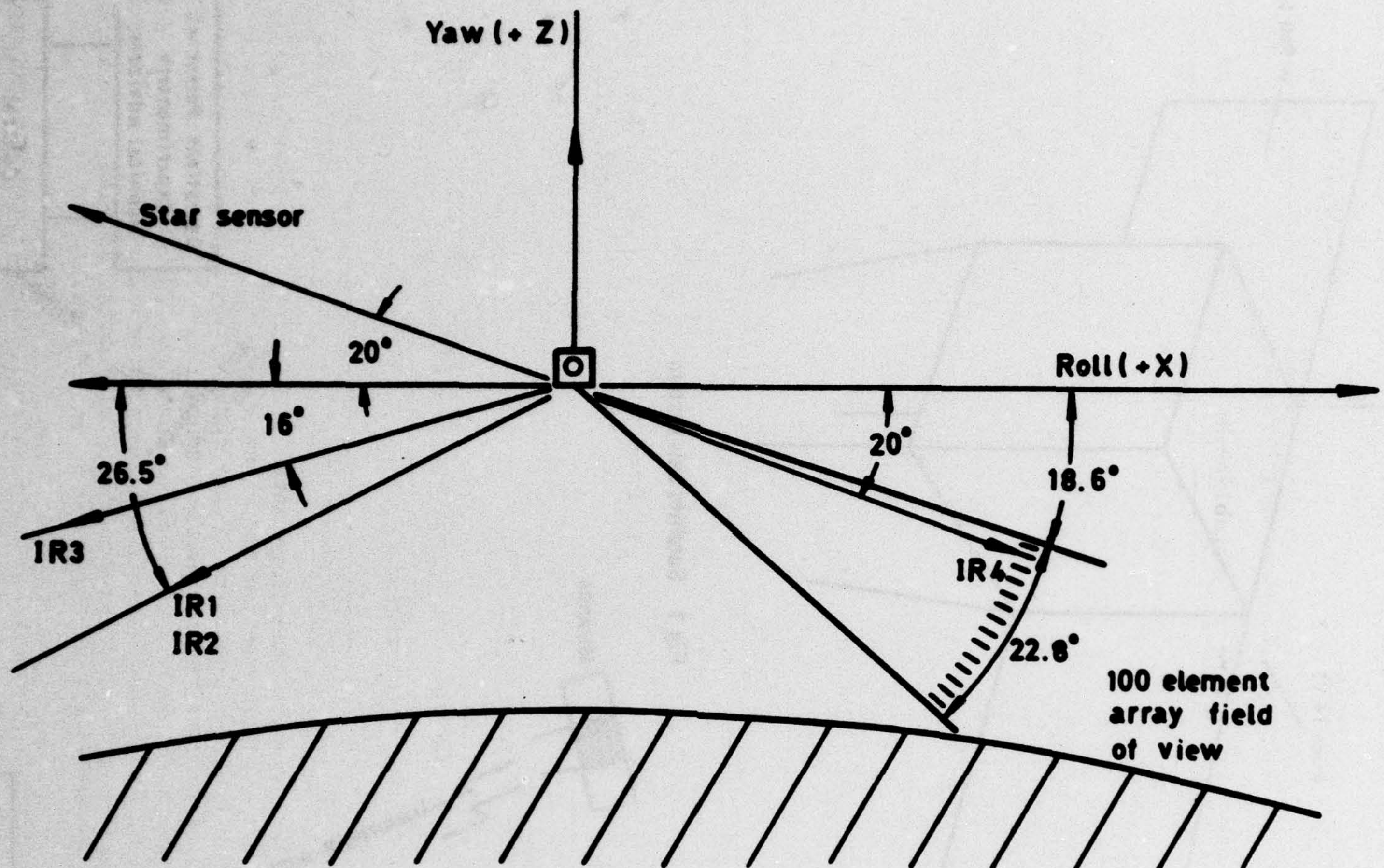


Fig 3 Miranda experimental sensors fields of view